Neutrino Factory and Muon Collider R&D

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FRA Visiting Committee
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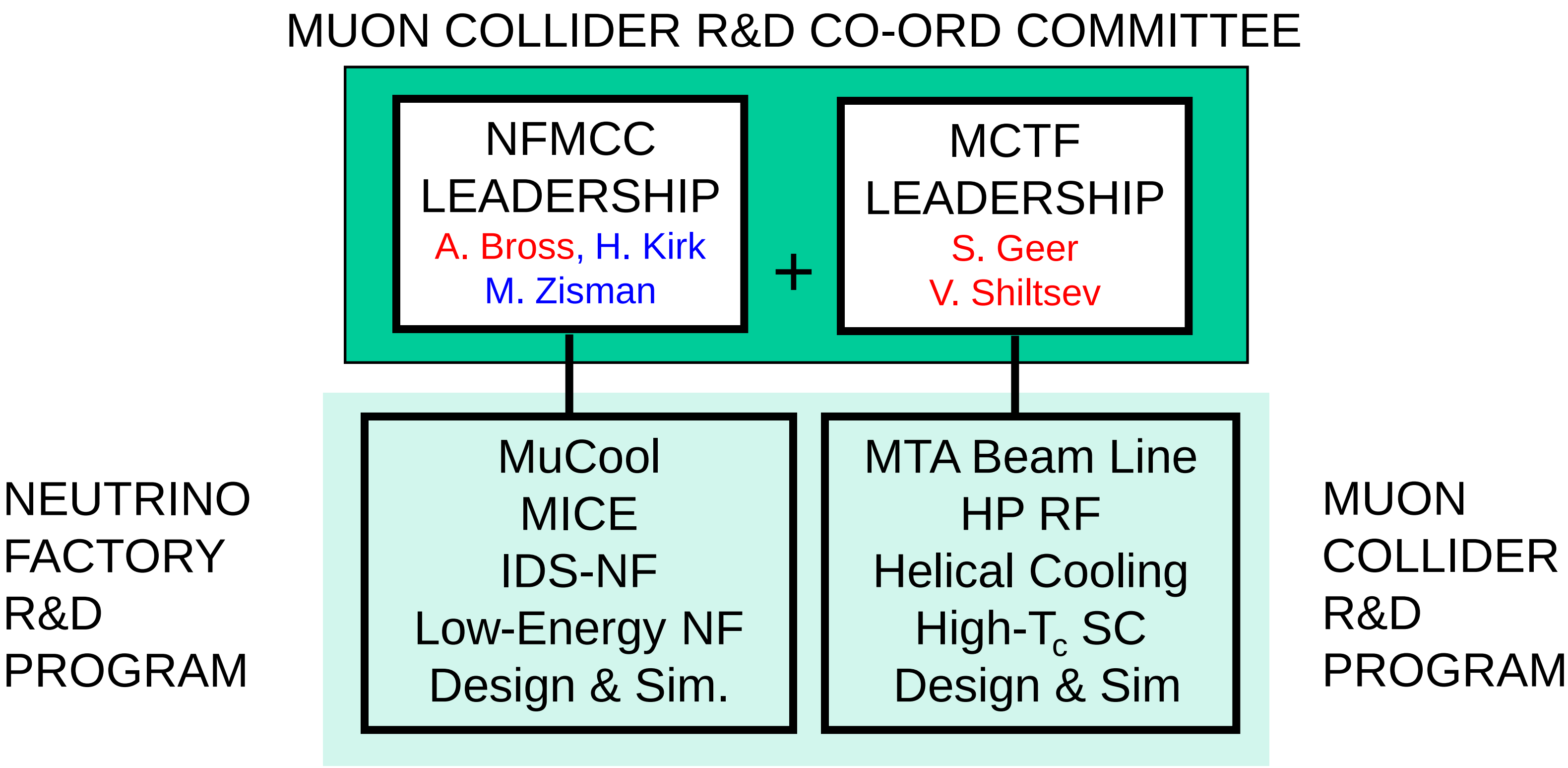
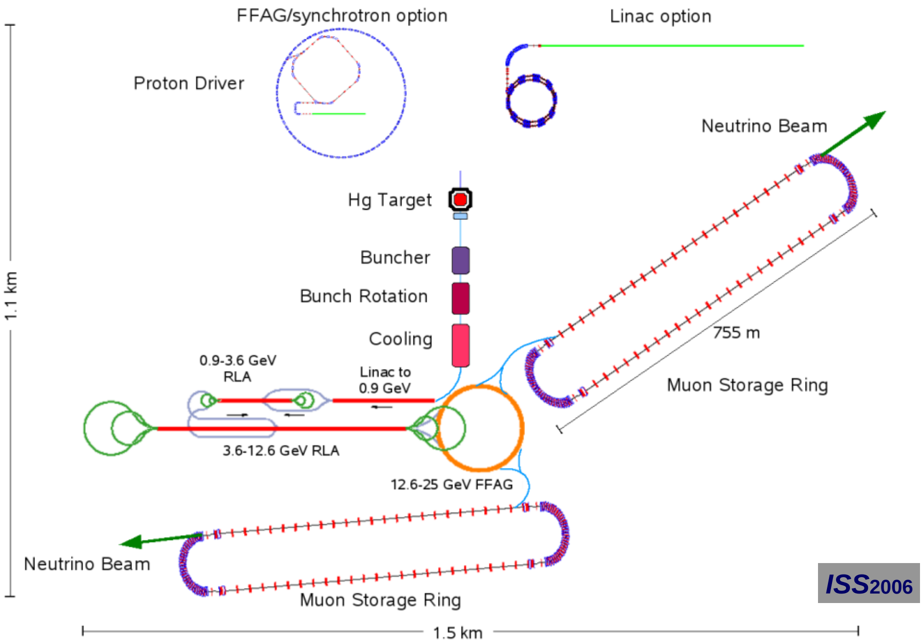
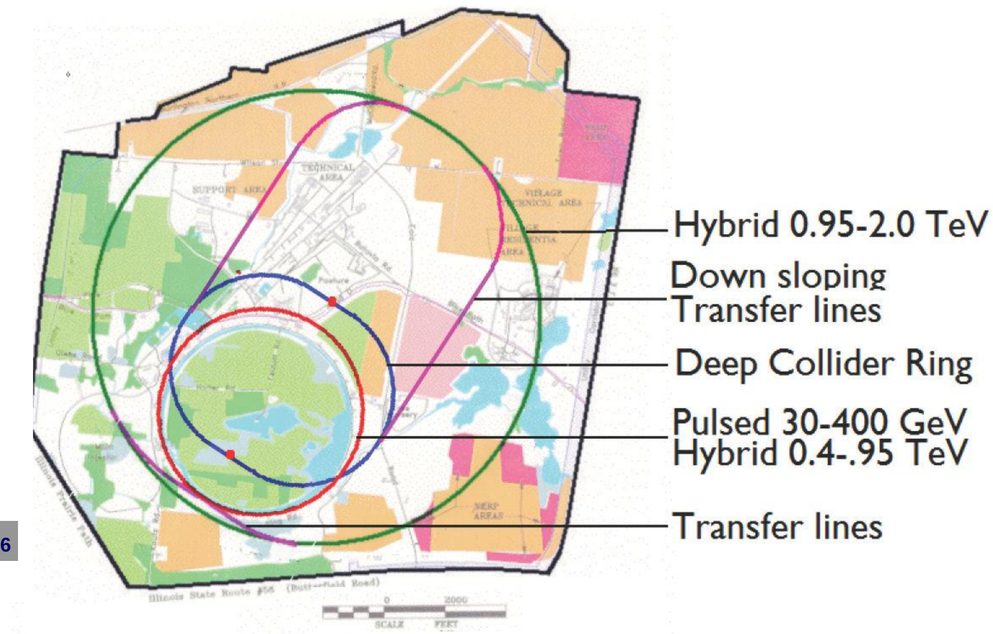
Neutrino Factory and Muon Collider R&D Organization

- R&D Program carried out by two groups
  - Neutrino Factory and Muon Collider Collaboration
  - Fermilab Muon Collider Task Force



NF & MC
Although Very Different – Front End Can be the Same



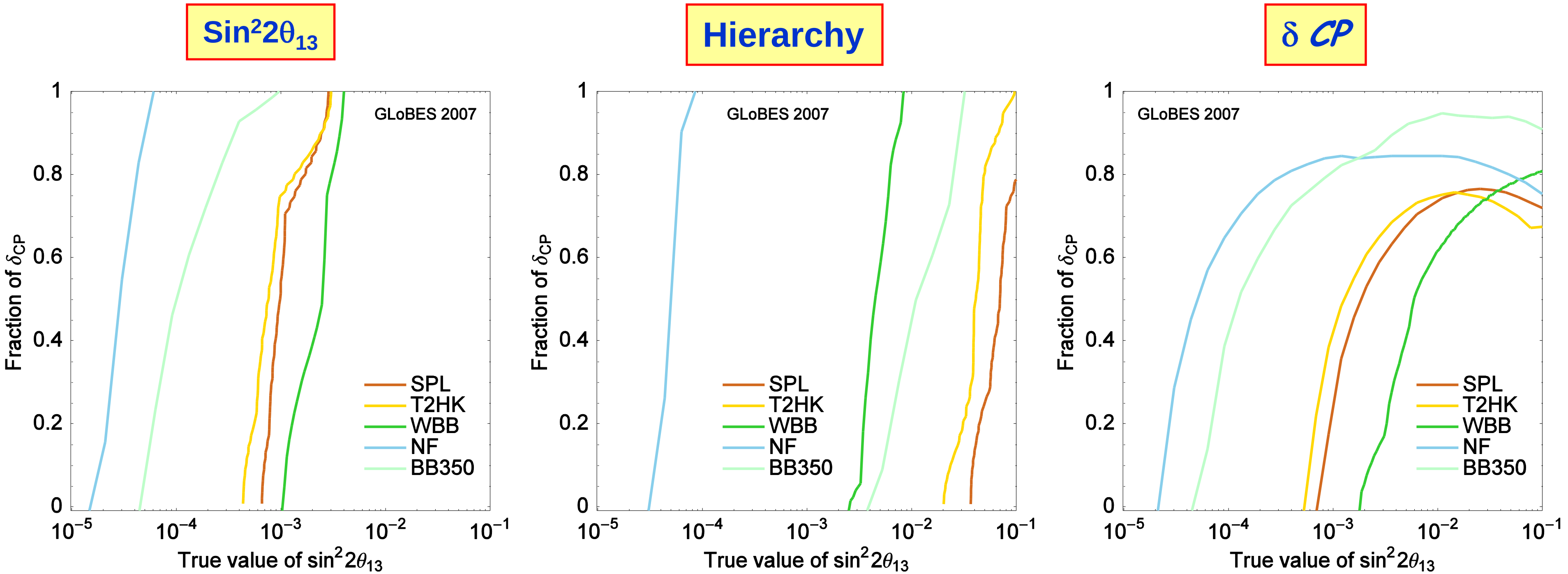


- Neutrino Factory
  - IDS Basline (FS1, FS2(a)(b), ISS)
    - 25 GeV μ storage ring
    - 4 GeV Option under study
- MC: One Concept
  - 4 TeV Center-of-Mass
    - Rapid-Cycling Synchrotron Acceleration

SMALL FOOTPRINT

NF Motivation - Physics Reach (ISS)

- The NF gives the best Physics Reach
  - NF ≡ PRECISION



SPL: 4MW, 1MT H_2OC, 130 km BL
T2HK: 4 MW, 1MT H_2OC, 295 km BL
WBB: 2MW, 1MT H_2OC, 1300 km BL

NF: 4MW, 100KT MIND, 4000 & 7500 BL
BB350: γ=350, 1MT H_2OC, 730 km BL

Muon Collider - Motivation

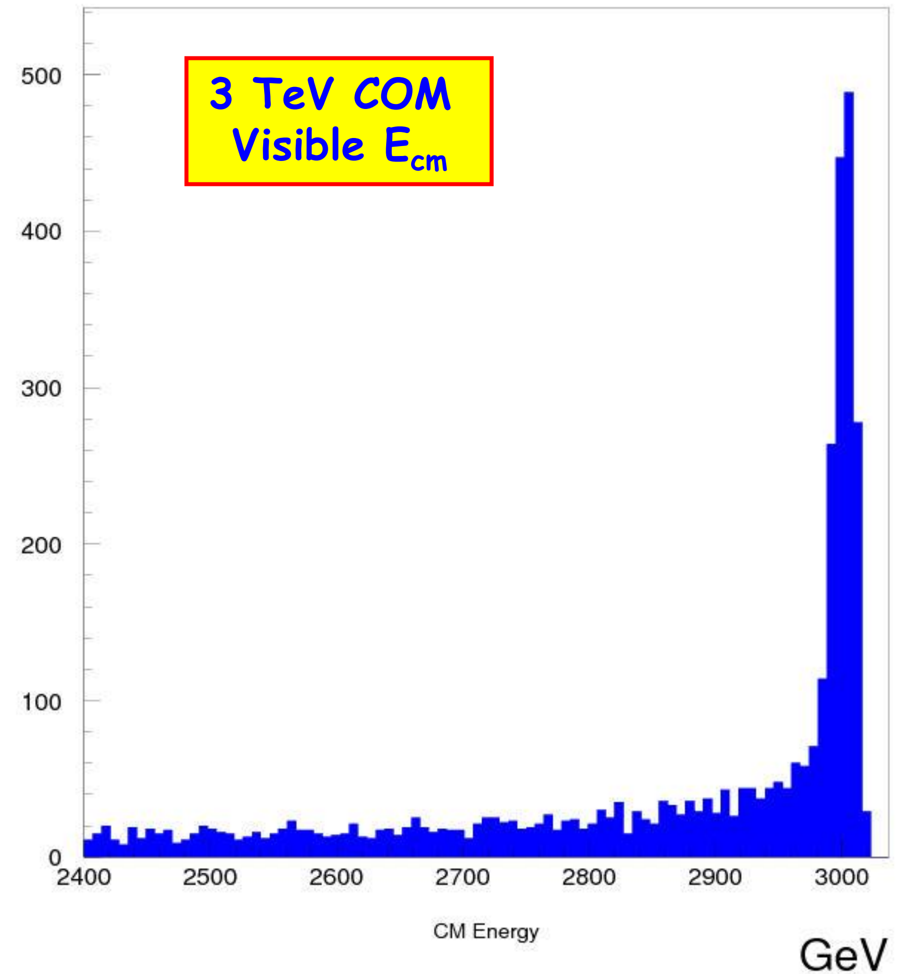
Reach Multi-TeV Lepton-Lepton Collisions at High Luminosity

Muon Colliders may have special role for precision measurements.
Small ΔE beam spread -
Precise energy scans

Small Footprint -
Could Fit on Existing Laboratory Site

Muon Collider at the Energy Frontier

- Comparisons with Energy Frontier e^+e^- Collider
  - For many processes - Similar cross sections
  - Advantage in s-channel scalar production
    - Cross section enhancement of $(m_\mu/m_e)^2$
      - $\approx 40{,}000$
  - More precise energy scan capability
    - Beam energy spread and Beamstrahlhung limits precision of energy frontier (3TeV) e^+e^- machines
  - Muon Decay backgrounds in MC do have Detector implications, however
- Started MC Physics and Detector Study Group
  - E. Eichten & C. Hill (Theory)
  - M. Demarteau (Detector)



The Future - *The Planets Will Be In Alignment?*

- We believe ~2012 will be a pivotal time in HEP
  - LHC Physics Results
  - Neutrino Data from Reactor and Accelerator Experiments
    - Double Chooz Daya Bay
    - MINOS, T2K ,Nova
  - Major Studies for Frontier Lepton-Colliders Completed
    - ILC EDR
    - CLIC CDR
- Many exciting results – Will point us in *Some* Direction
  - We Don't Know Which One Yet

Aspirational Goals for 2012

- Simulation Effort
- Component Development
- Experimental Studies

Aimed at Delivering

- Completed IDS-NF Study
  - RDR
- Completed MC Feasibility Study
  - ZDR

Needs Common to NF and MC Facility

- Proton Driver
  - Project X
- Target, Capture, and Decay
  - create π's; decay into μ's
- Phase Rotation
  - reduce ΔE of bunch
- Cooling
  - reduce emittance of the muons
    - Cost-effective for NF
    - Essential for MC
- Acceleration
  - Accelerate the Muons
- Storage Ring
  - store for ~1000 turns

80% Overlap in initial R&D

But there are Key Differences

Neutrino Factory

- Cooling
  - Reduce transverse emittance
    - $\varepsilon_\perp \sim 7$ mm
- Acceleration
  - Accelerate to 25 GeV
    - May be as low as 5-7 GeV
- Storage Ring
  - No intersecting beams

Muon Collider

- Cooling
  - Reduce 6D emittance
    - $\varepsilon_\perp \sim$ 3-25 μm
    - $\varepsilon_L \sim$ 70 mm
- Acceleration
  - Accelerate to 1-2 TeV
- Storage Ring
  - Intersecting beams

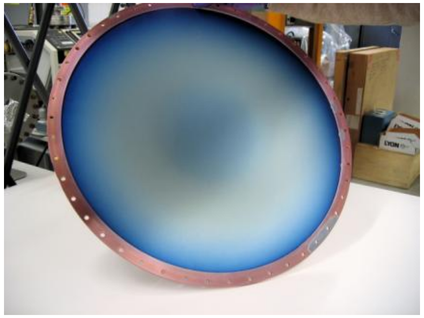
R&D Program

Focusing on Fermilab Activities

Muon Cooling: MuCool and MICE

Component R&D and Cooling Experiment

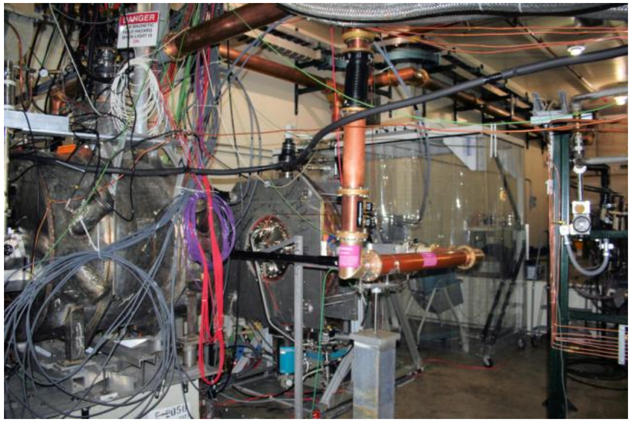
- MuCool
  - Component testing: RF, Absorbers, Solenoids
    - With High-Intensity Proton Beam
  - Uses Facility @Fermilab (MuCool Test Area -MTA)
  - Supports Muon Ionization Cooling Experiment (MICE)
  - 10 institutions from the US, UK and Japan participate



50 cm ∅ Be RF window

MuCool Test Area

MuCool
201 MHz RF Testing



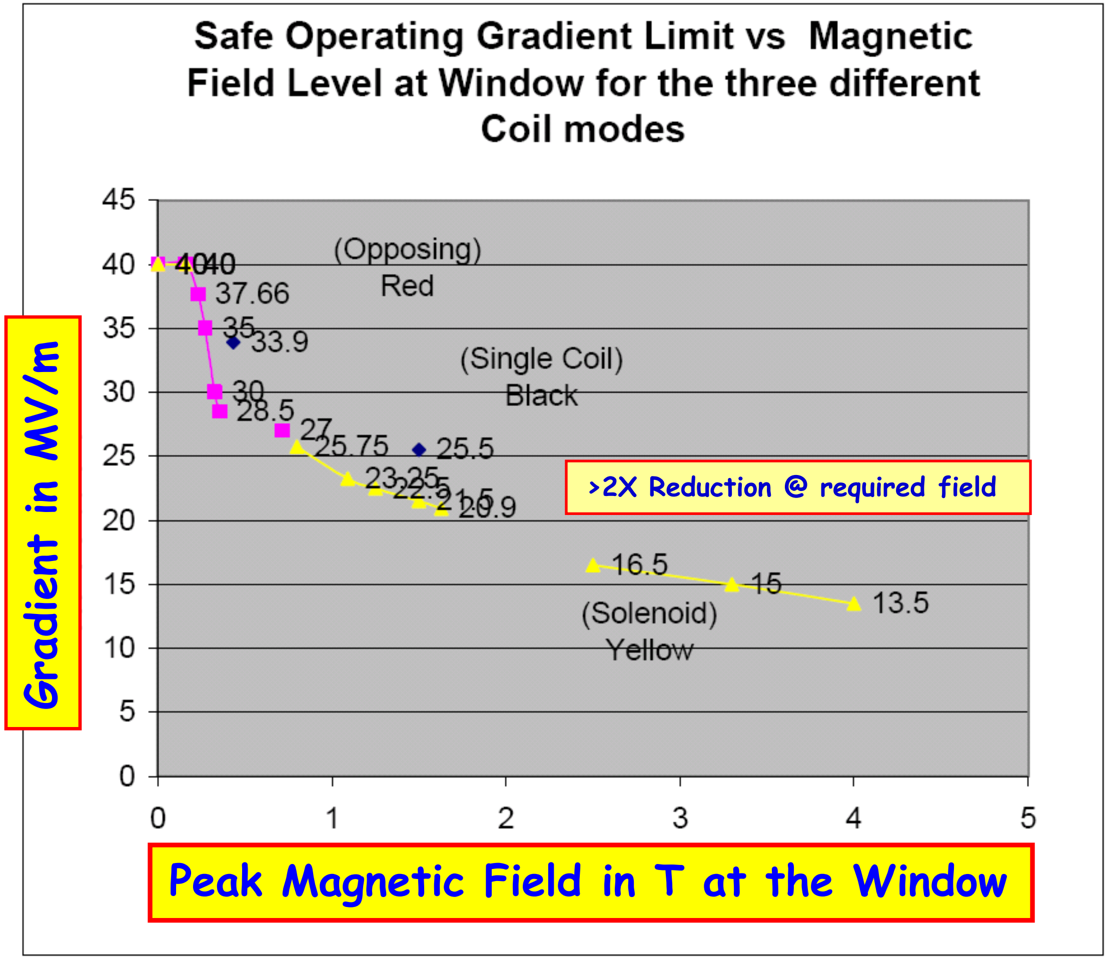
MuCool
LH_2 Absorber
Body

Fundamental Focus Of RF R&D

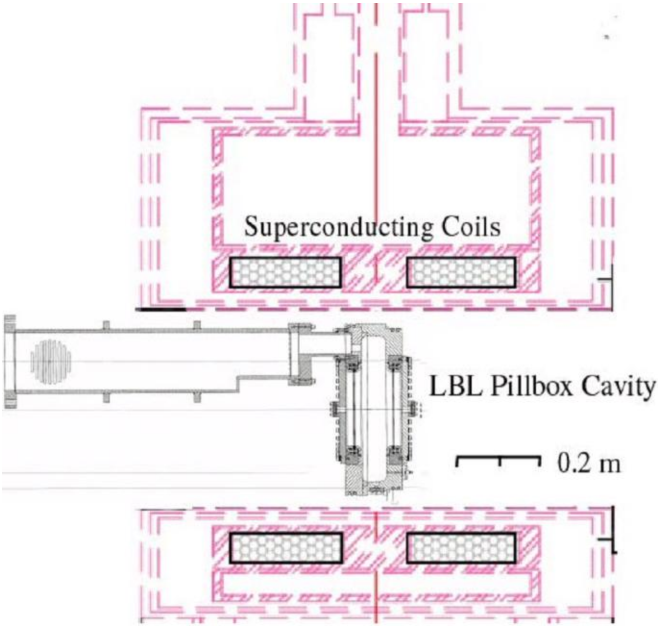
- Study the limits on Accelerating Gradient in NCRF cavities in magnetic field
- It has been proposed that the behavior of RF systems in general can be accurately described (predicted) by universal curves
  - Electric Tensile Stresses are important in RF Breakdown events
- This applies to all accelerating structures
- Fundamental Importance to both NF and MC
  - Muon capture, bunching, phase rotation
  - Muon Cooling
  - Acceleration

The Basic Problem – B Field Effect

805 MHz Studies



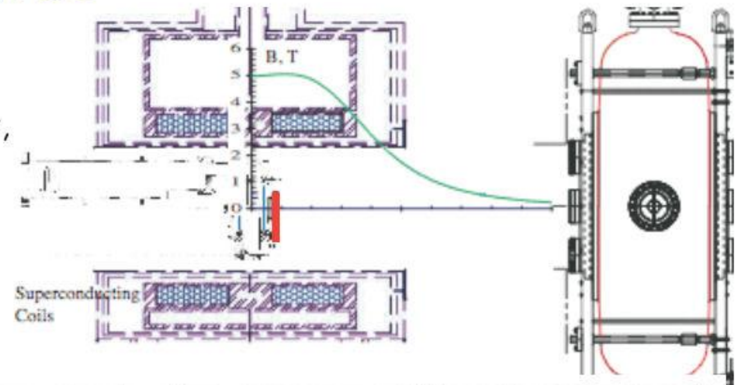
- Data seem to follow universal curve
  - *Max stable gradient degrades quickly with B field*
- Remeasured
  - *Same results*



805 MHz Imaging

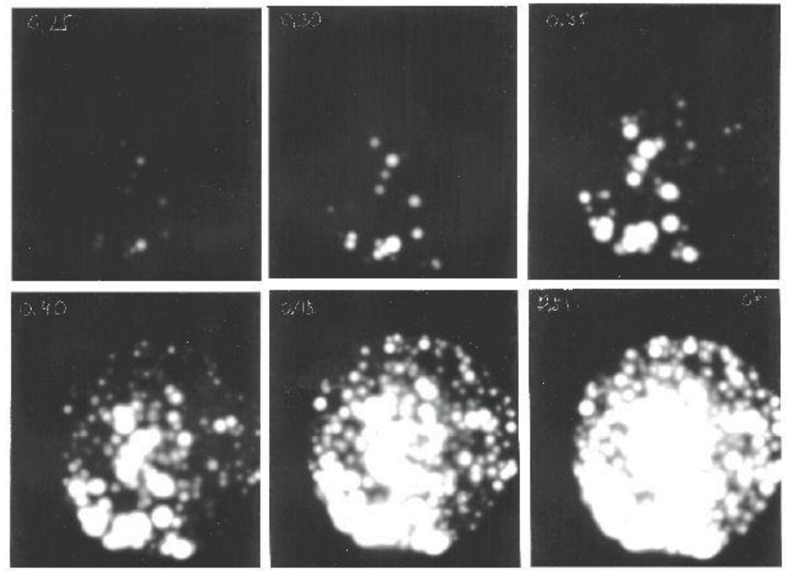
Polaroid Pictures of Field emitters

- Inserting polaroids near the window,



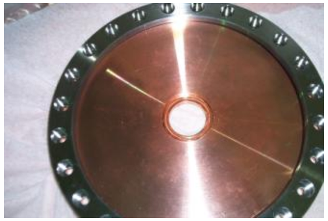
- Gives a picture of how the field emitters change with rf field.

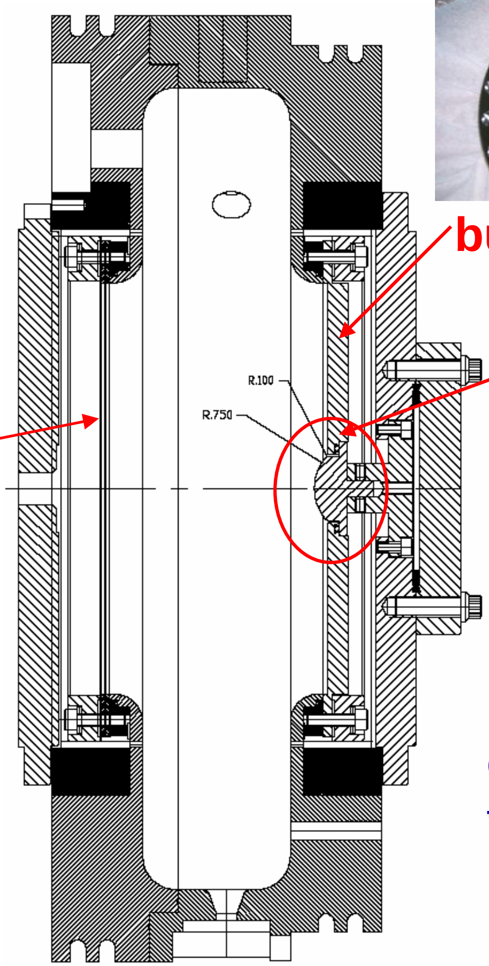
  8.8 – 17.6 MV/m



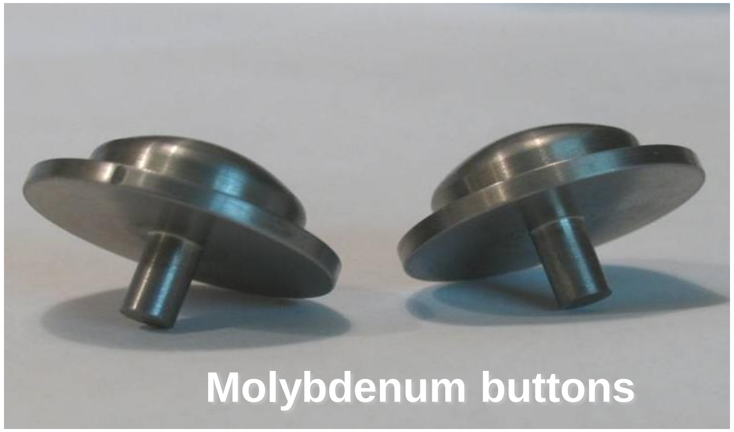
Cavity material ("Button") test

- "Button" system in pillbox cavity designed for easy replacement of test materials
- Tested so far: TiN-coated Cu & Mo, bare Mo and W
- To be tested: Cu (electro-polished & unpolished), Be
- Results to date indicate that TiN can improve performance at a given B field by somewhat more than 50%
  - 16.5MV/m → 26MV/m





(*1.7x* field enhancement factor on button surface)



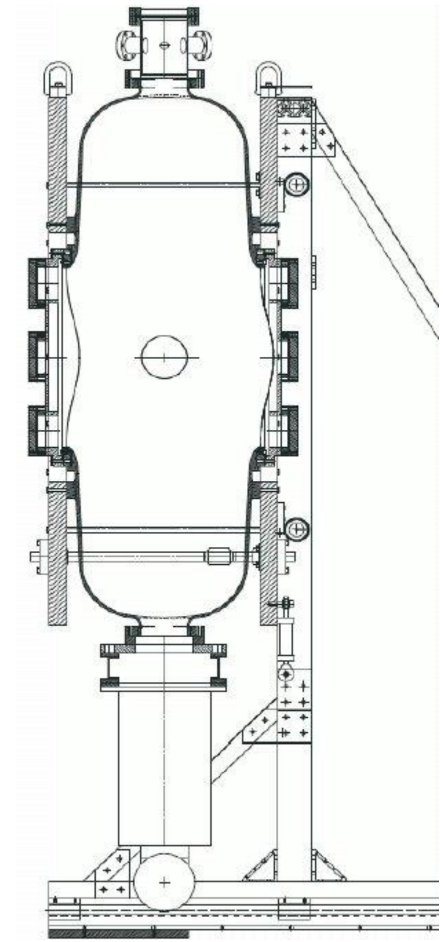
Molybdenum buttons

MCTF

RF R&D – 201 MHz Cavity Test

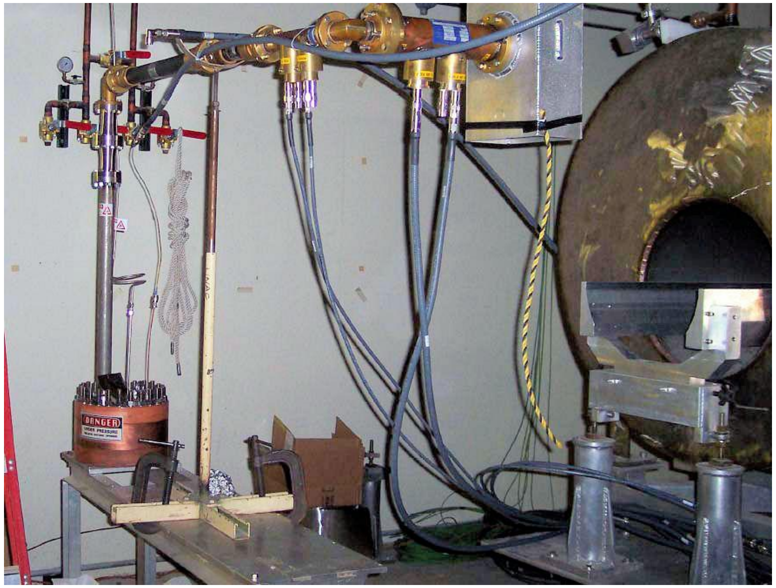
The 201 MHz Cavity – *19 MV/m Gradient Achieved* (Design – 16MV/m)

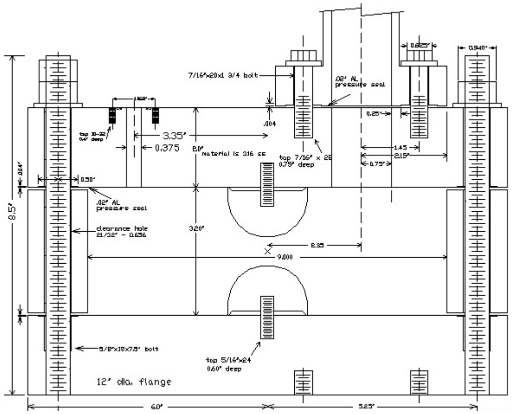
- At 0.75T reached 14MV/m (multipactoring observed)

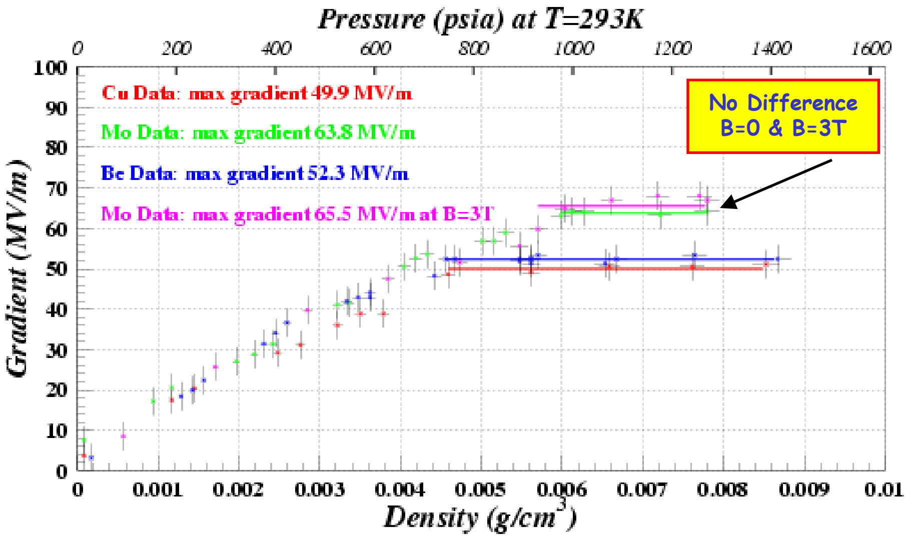


High Pressure H_2 Filled Cavity Work - Muon's Inc

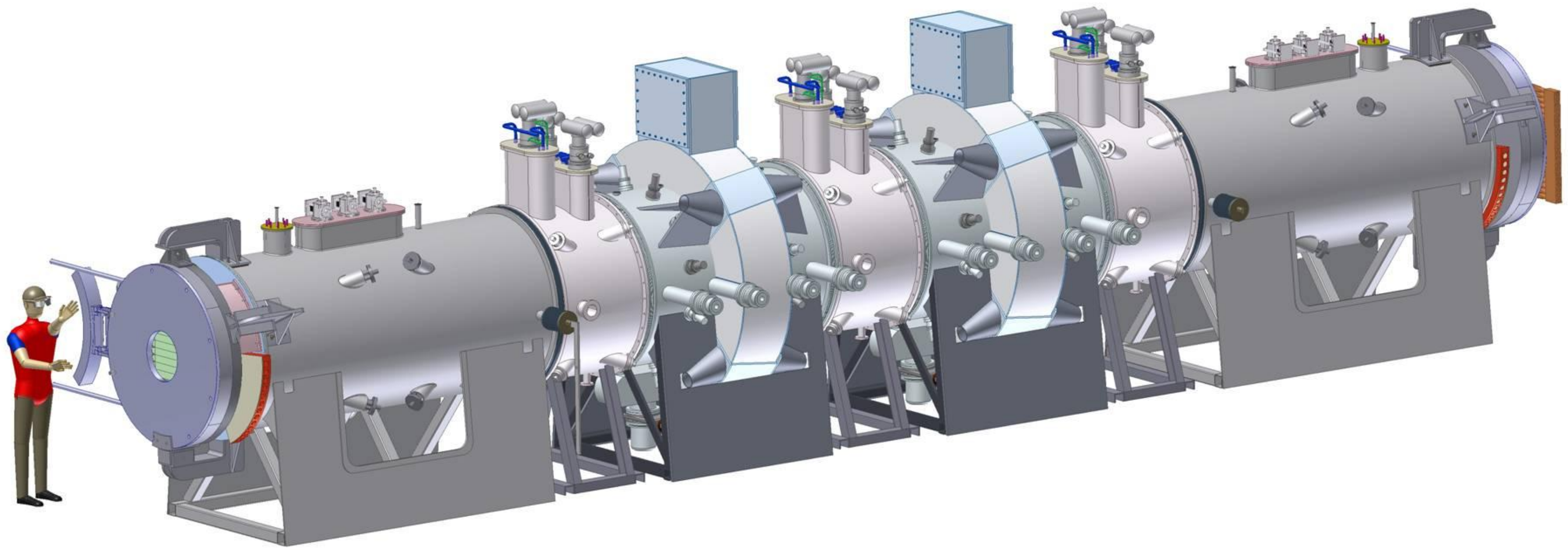
- High Pressure Test Cell
- Study breakdown properties of materials in H_2 gas
- Operation in B field
  - No degradation in M.S.O.G. up to ≈ 3.5T
- **Next Test – Repeat with beam**



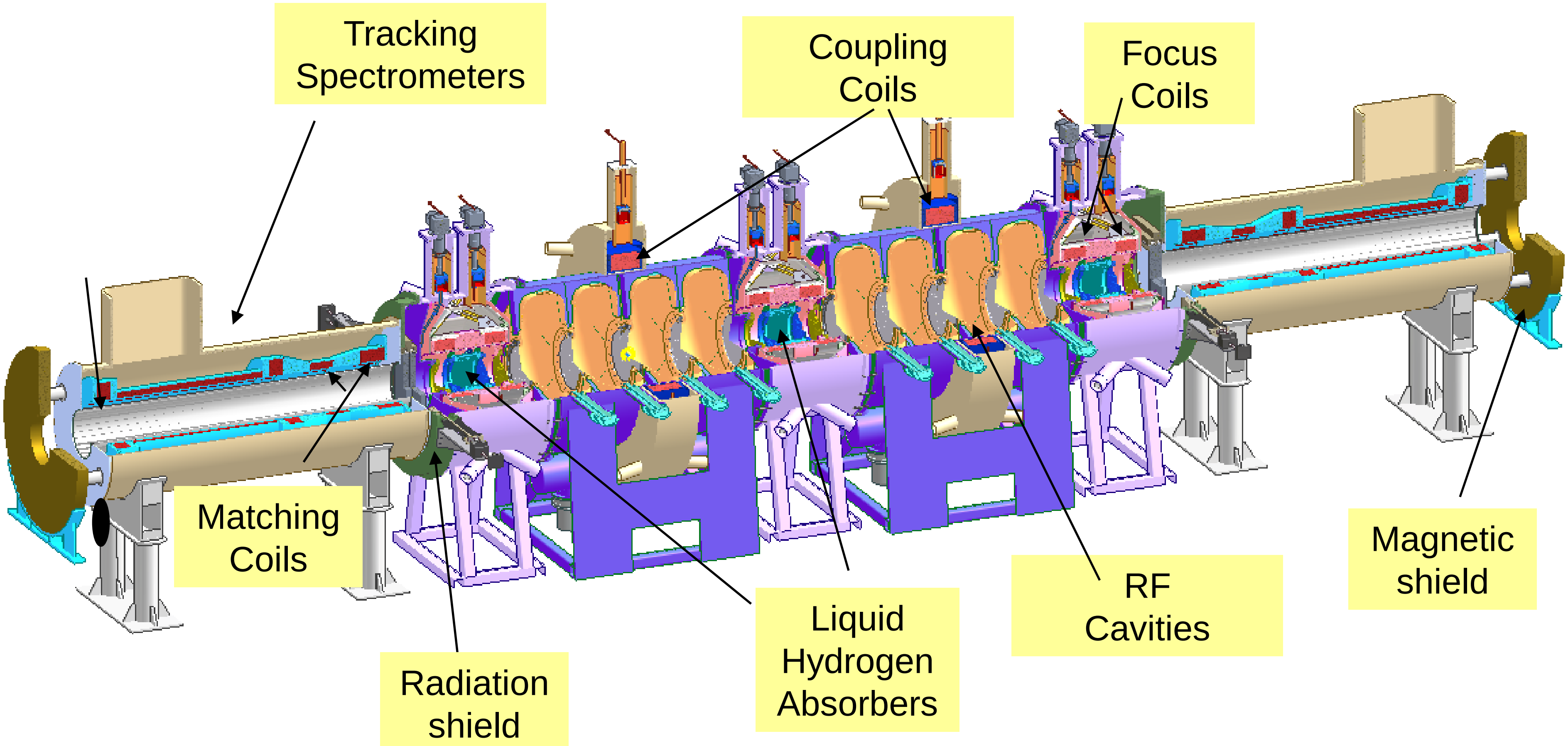




Muon Ionization Cooling Experiment (MICE)



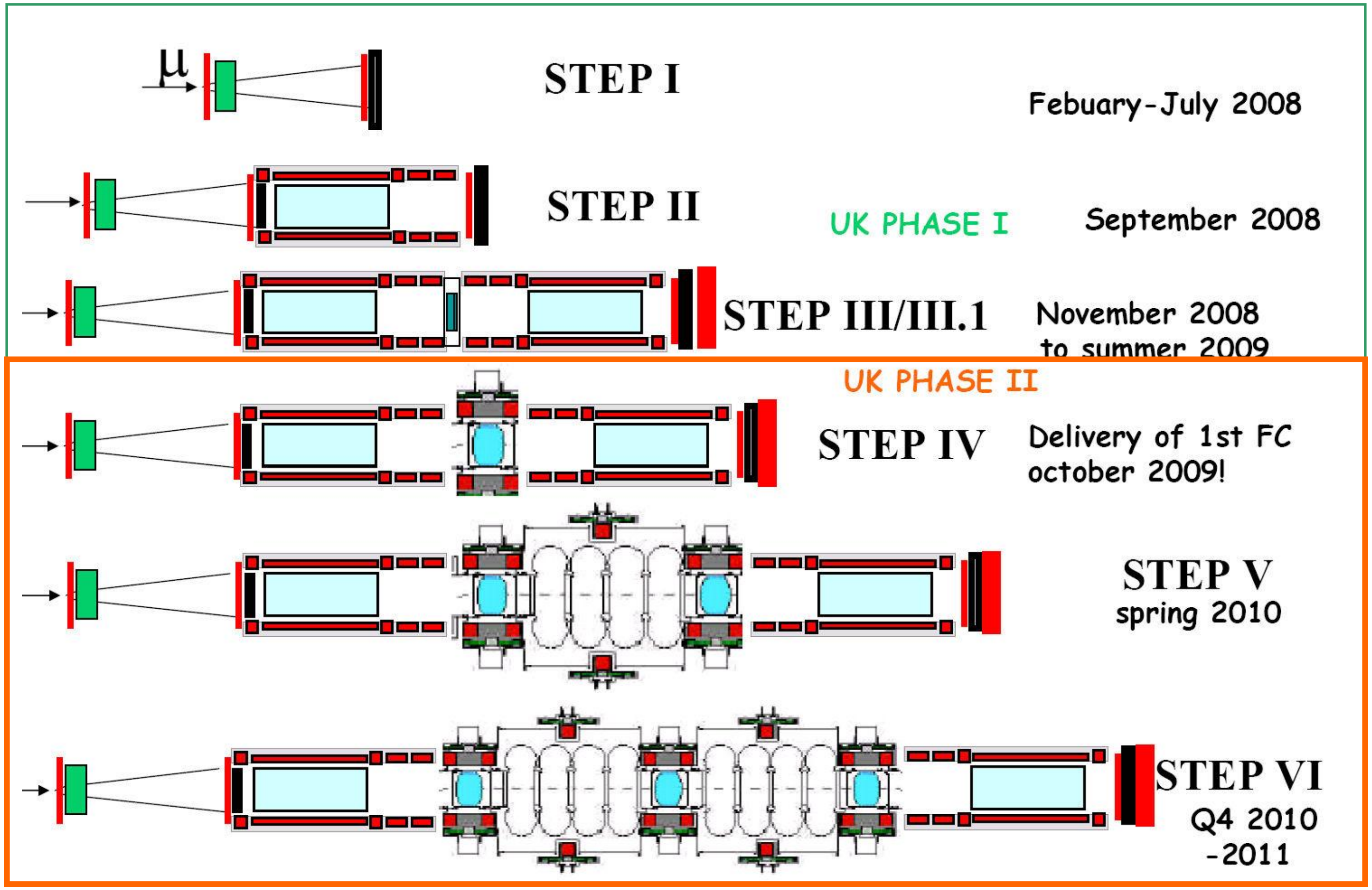
Muon Ionization Cooling Experiment



Muon Ionization Cooling Experiment (MICE)

MICE
Measurement of Muon Cooling - Emittance Measurement @ 10^{-3}

Aspirational MICE Schedule as of April 2008



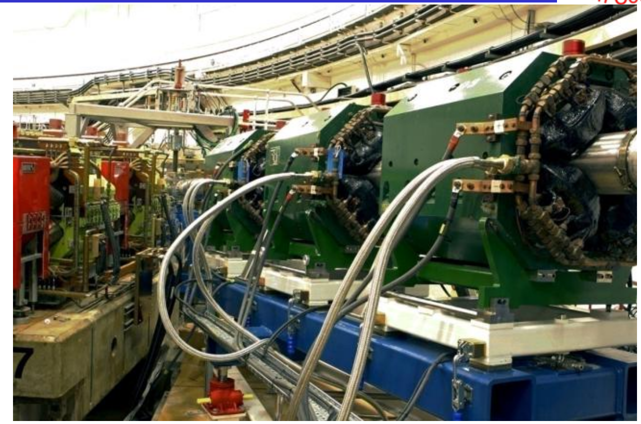
MICE Milestone

First Beam Measured in MICE Beam Line

View Through Two of the Quads in the MICE Beam Line

Progress on MICE

- Beam Line Complete
  - First Beam March 30th!
    - Beam Monitors (FNAL)
- First Spectrometer Summer

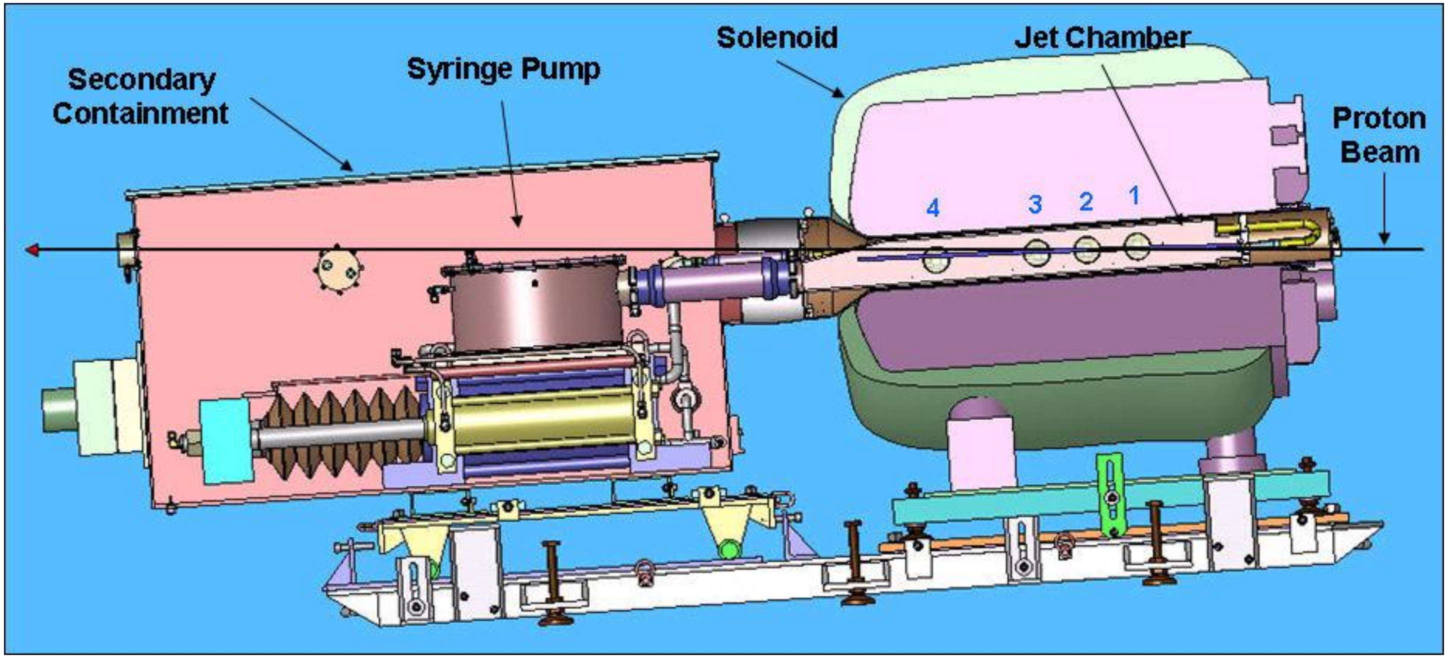


Fermilab Responsibilities in MICE

- Beam Line
  - Beam Line monitors (scintillating fiber detectors)
- Spectrometers
  - Fiber ribbons for Fiber Tracker
  - Fiber Readout
    - VLPC and cryogenics
    - Analog Front-end Board
  - Field mapping of Spectrometer magnets
    - Using upgraded ZipTrack System
- Absorbers
  - Supported testing of prototype (KEK design) LH_2 @MTA
  - Provide LiH disks for step III.1

MERIT -Mercury Intense Target

- Test of Hg-Jet target in magnetic field (15T)
- Located in TT2A tunnel to ISR, in nTOF beam line
- Beam run was in October, 2007
  - Test the principle of 50 Hz operation at 24 GeV $\Rightarrow$ 4 MW

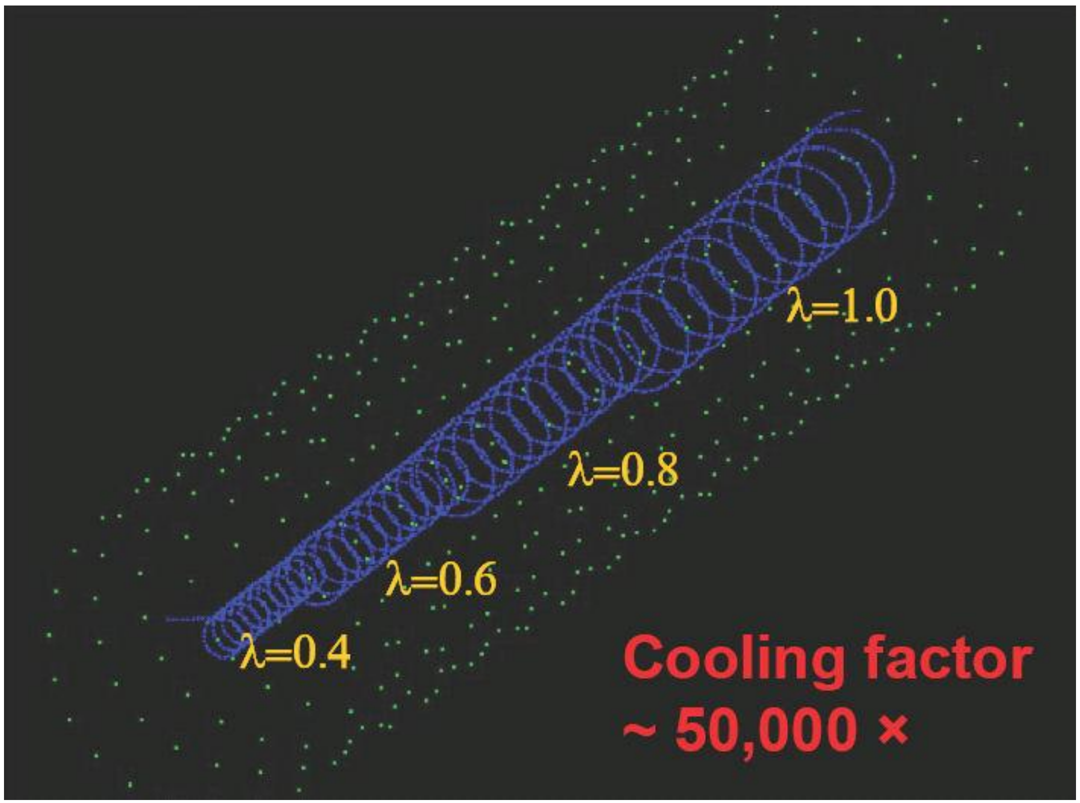


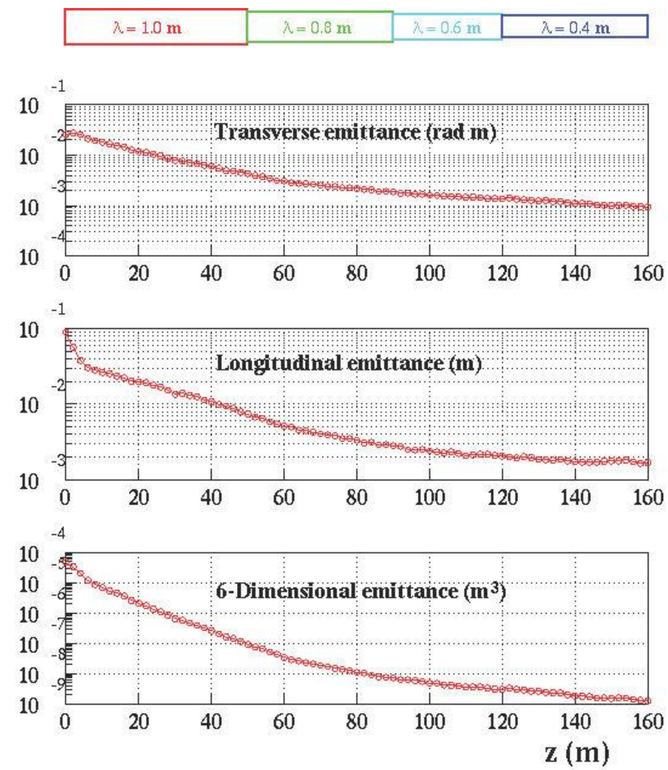
The MERIT Experiment Results

- The Neutrino Factory/Muon Collider target concept has been validated for 4MW 50Hz operations.
  - Tremendous work by the MERIT Team
- Data Analysis continues
  - APC – Energy Deposition Group
    - Particle production/flux simulations and compare to data

Helical Cooling Channel - Muons Inc

- Magnetic field is solenoid B0+ dipole + quad
- System is filled with H2 gas, includes rf cavities
- Cools 6-D (large E means longer path length)
- **But, incorporating RF is Engineering challenge!**

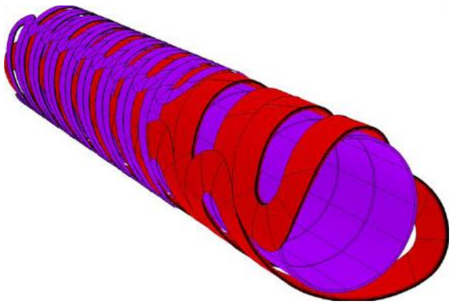


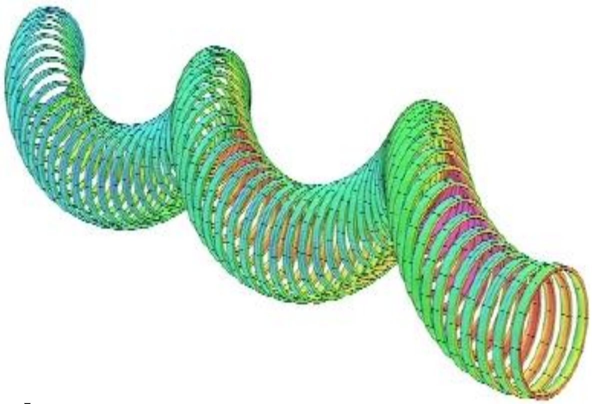


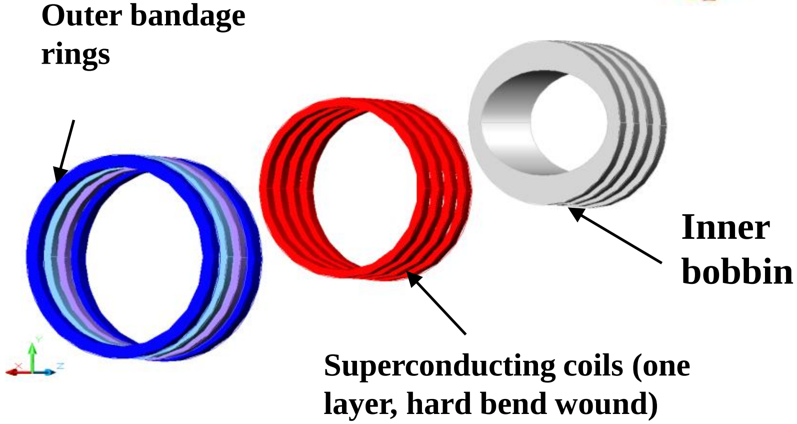
MCTF

HCC Magnet design – Fermilab TD

- Helical solenoid (HS): Smaller coils than in a "snake" design
  - Smaller peak field
  - Lower cost
- Field components in HS determined by geometry
  - Over constrained
  - Coil radius is not free parameter
- 4 Coil Demonstration Model
  - Validate mechanical structure and fabrication methods
  - Study quench performance and margins, field quality, quench protection
  - Use SSC conductor







4-coil fabrication status

Parts:
- design complete
- procurement in progress

Cable:
- Extracted strand samples were tested

Practice winding complete:
- cable stability and support during hard bend winding
- coil size control

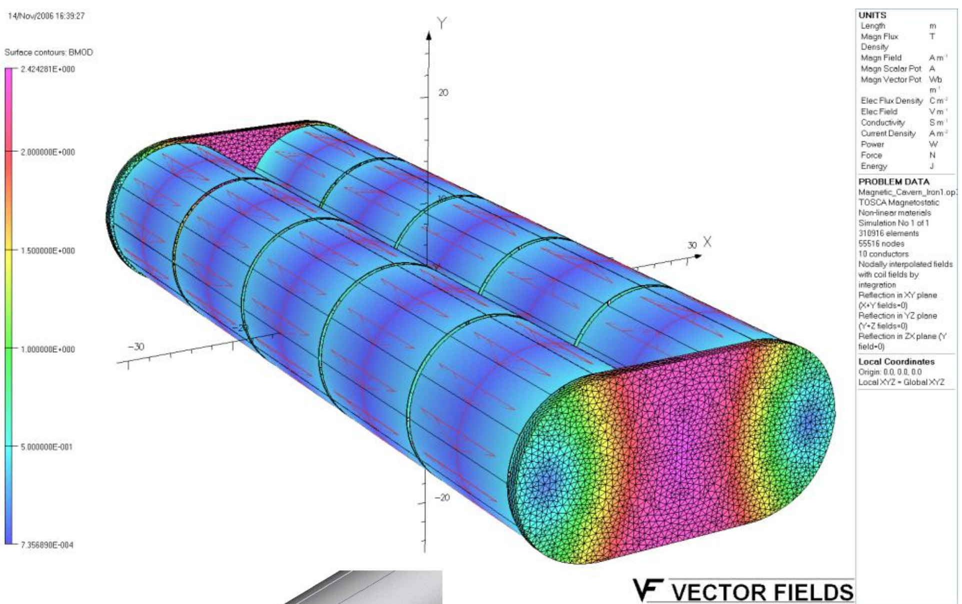
Instrumentation:
- development started

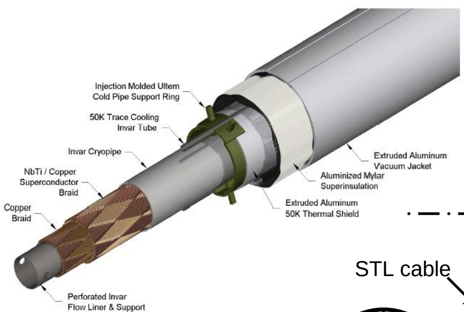
Model test:
- September 2008

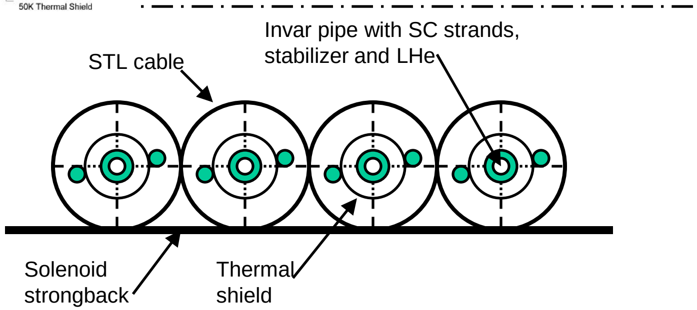
MCTF Conductor Program: Extreme-High-Field Magnets

- Several schemes for the final stage(s) of muon cooling for the MC require 30-50T solenoids ⇒ High Temperature Superconductor R&D
- We are working to form a National HTS R&D Program
  - Address very-high magnet R&D in general
- Emphasis on HTS strands, tapes and cables
  - Nb3Sn and Nb3Al strand and cable R&D is supported by other programs (DOE, LARP, NIMS/FNAL/KEK, CARE, etc.)
- Fermilab R&D infrastructure
  - Two Oxford Instrument Teslatron stations with 16T and 17T solenoids, and test temperatures from 1.9K to 70K
  - 42-strand cabling machine
  - Probes to measure
    - I_c of HTS strands and tapes as a function of field, temperature, and field orientation
    - Transverse pressure sensitivity of strand I_c in a cable
  - 28 kA SC transformer to test cables at self-field in LHe

Very-Large Magnets: NF Detector R&D
The Magnetic Cavern



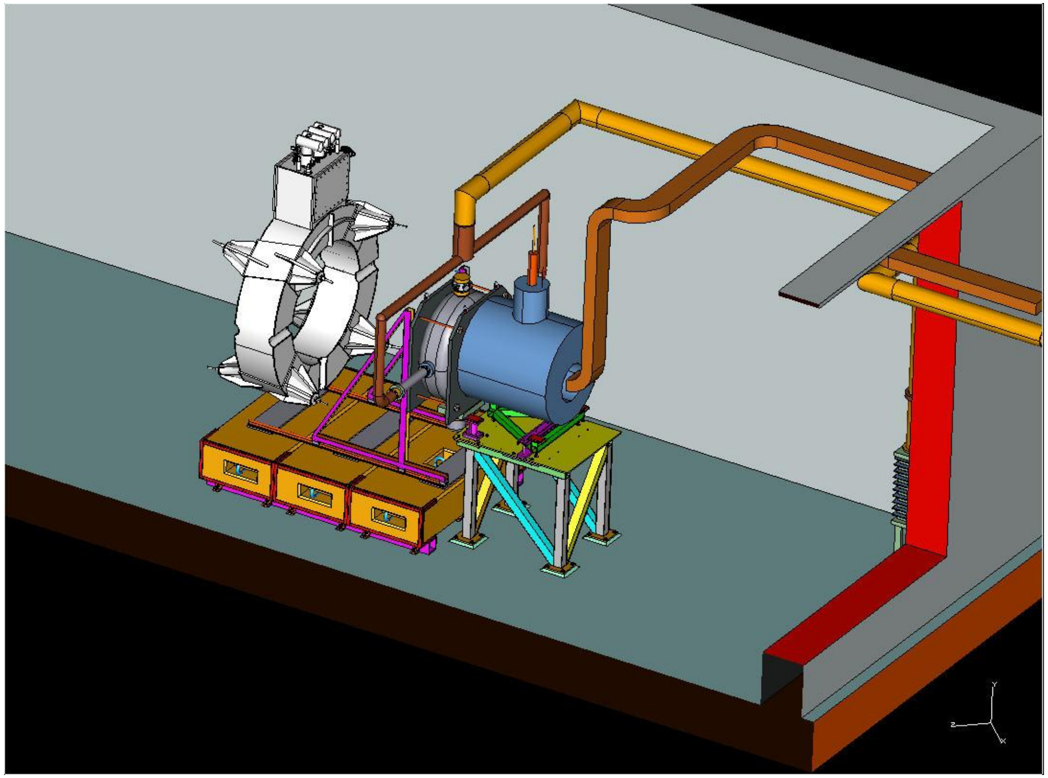




- Based on Superconducting Transmission Line (SCTL) for VLHC (Fermilab)
- Features
  - ➢ 25 X 10^3 m^3
  - ➢ 10 solenoids
  - ➢ 15-m long 15 m ID each
  - ➢ B_{nom}~0.5 T (@50% critical current)
  - ➢ 1 m iron wall, B~2.4 T
  - ➢ Good field uniformity
- Re-engineer SCTL for tighter bend radius
  - ➢ 7.5m vs. 37km
- 2-3 Turn full-scale prototype tests
  - ➢ Verify forces, etc

MuCool Phase II

MuCool Phase II



- Commission Linac Beam Line to MTA
- Reconfigure Equipment
- First Beam Experiment (Muon's Inc HP RF Test Cell) by end of 2008
- Tests of 201 MHz cavity in full field
    - New SC coil
        - MICE CC prototype

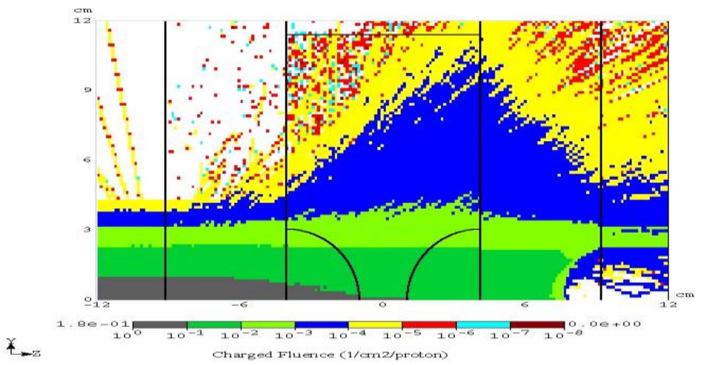
MTA Beam Status/Commissioning

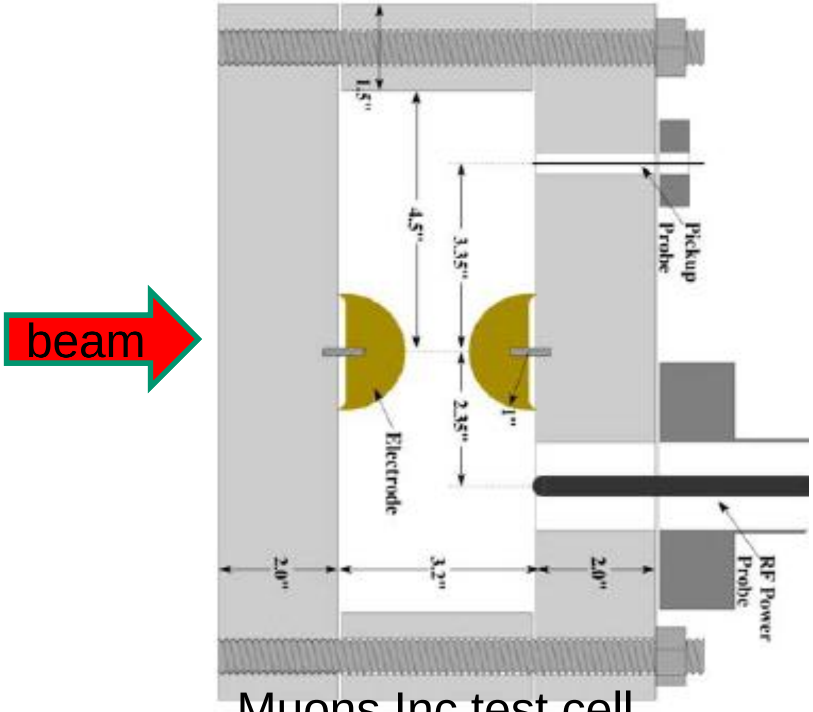
- Beam Line Installation Complete
- Beam Line commissioning to first beam stop (Linac side of shield wall) may start as early as June
- Still doing radiation shielding assessments
  - Rerouting RF Power required
    - Final configuration for this still being developed
- Will start at low intensity
  - Need Shielding upgrade (over-burden) for high-intensity
    - Full pulse intensity, limited #pulses/min

First Beam Experiment in MTA

Test of Muons Inc High Pressure H_2 805 MHz test cell

- Beam tests will be done in collaboration with Muons Inc
- First test will use the existing Muons Inc test cell
  - Will indicate direction of follow-ups experiments
- Linac 400MeV proton beam can generate ionization levels similar to muon beam.
  - About 50% of protons make it into cavity, at ~100MeV/c
  - Each proton ~5 MIPs
  - 6e12 protons ~1.2e13 muons
- If successful, next step is to build realistic 805 MHz test cavity





Muons Inc test cell

The Way Forward?

Muon Complex Vision

Road to a Neutrino Factory

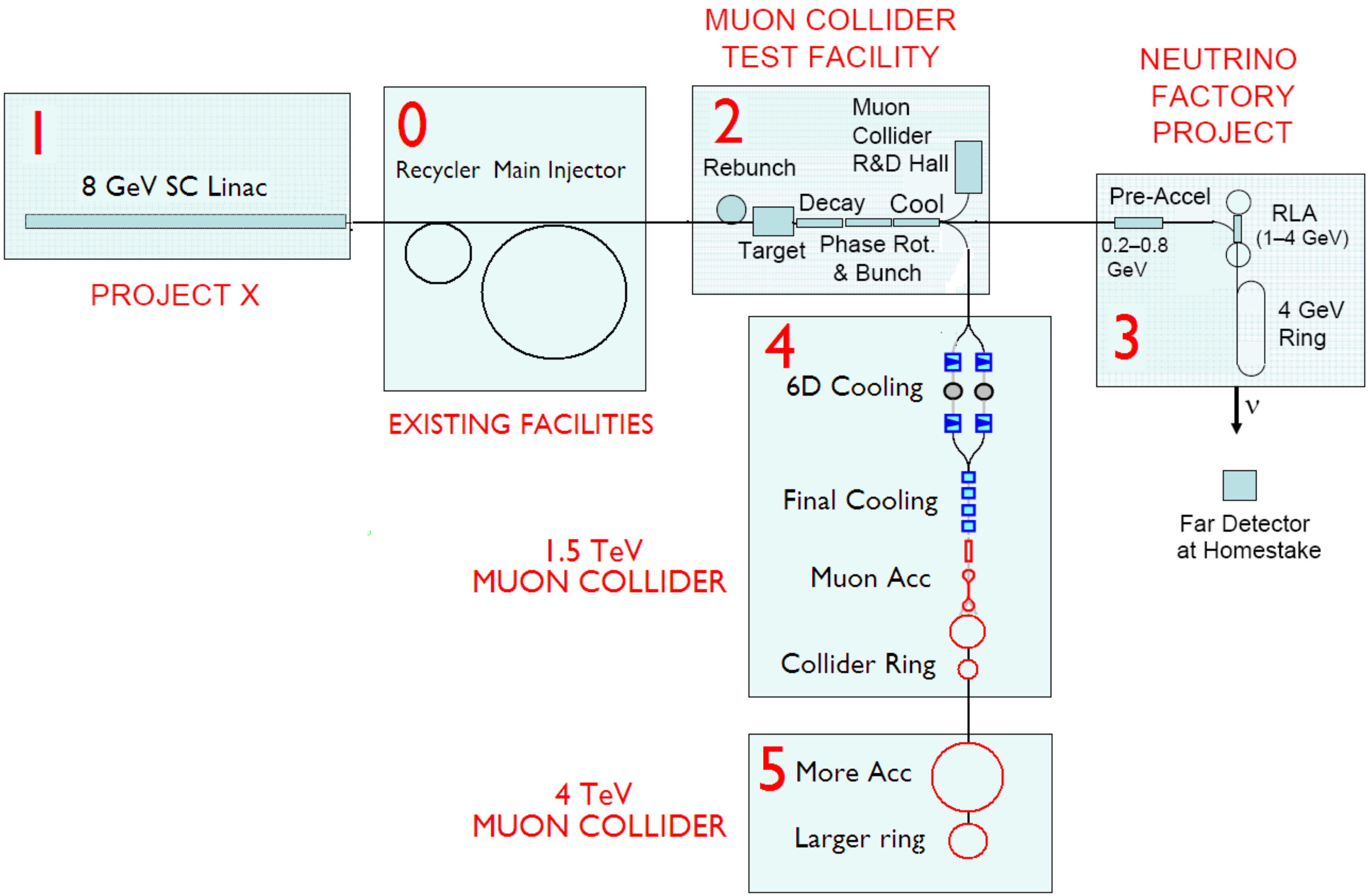
- The ISS
  - Made the case for the high-sensitivity programme of neutrino-oscillation measurement
    - Unprecedented physics reach and precision
  - Developed an internationally agreed baseline for the Neutrino Factory accelerator complex
  - Developed an internationally agreed baseline for the Neutrino Factory neutrino-detection systems
  - Demonstrated the need to evaluate the performance of cost of the various facilities, and the Neutrino Factory in particular, on the timescale of 2012 (RDR)
- This is the launch point for the IDS-NF
  - Physics performance of the Neutrino Factory is detailed and the specification of each of the accelerator, diagnostic, and detector systems that make up the facility is defined leading to a **RDR**

Road to the Muon Collider

- The MC could be the most cost-effective route to the Energy Frontier for a Lepton-Lepton Collider
  - The facility has tremendous physics potential
- MC ZDR by ≈ 2012 - Ingredients
  - End-to-End MC design
    - Technology Choice
  - MICE experiment (successful) results
  - Key RF questions answered
    - Technology Choice
  - Prospects of HTS magnets understood
    - Technology Opportunity
  - Muon acceleration techniques explored

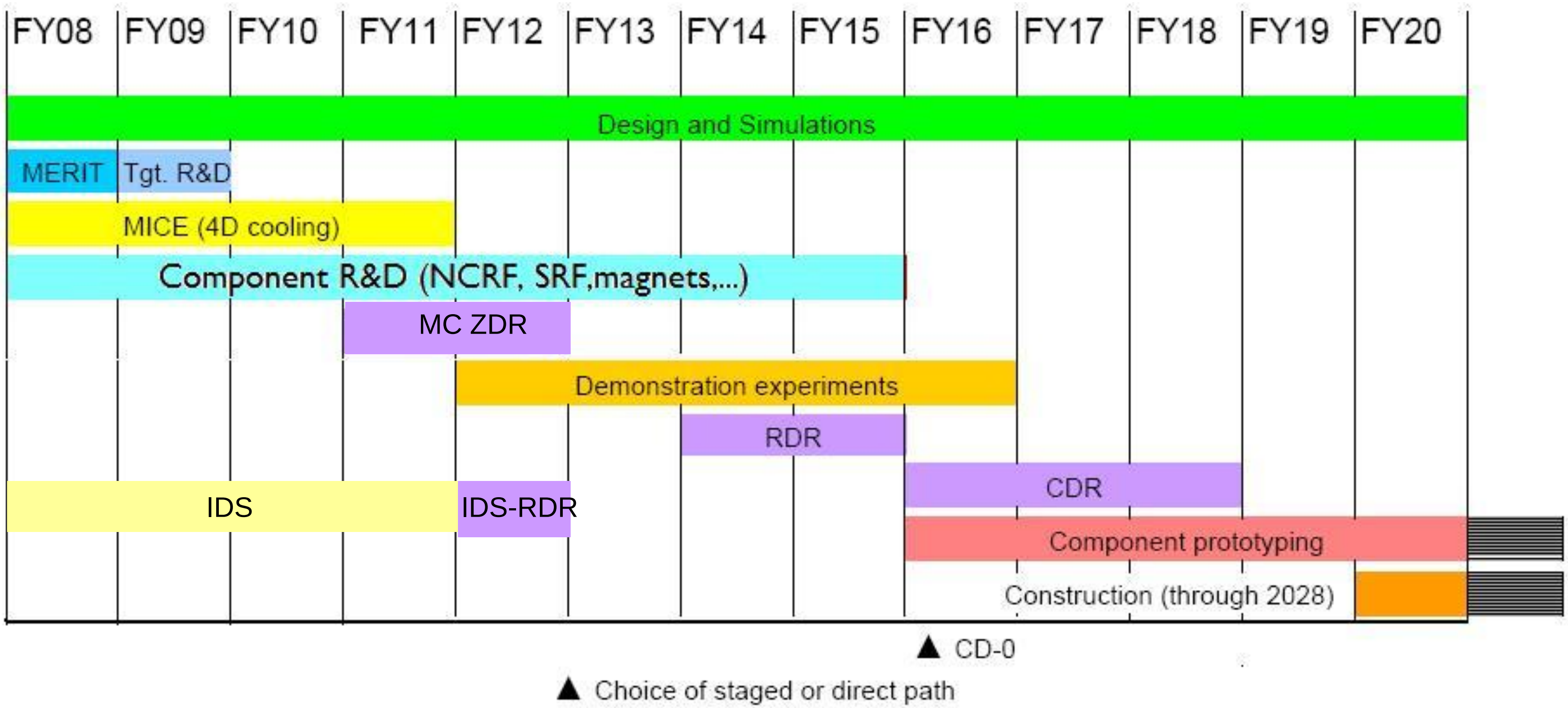
There is an Evolutionary Path

Muon Complex Evolution



MCTF

Timeline and Funding Request: *IDS RDR & MC FS*



8	11	13	20	25	25	25	35	40	40	R&D Funds M$/year

Muon Accelerator Research Program Organization

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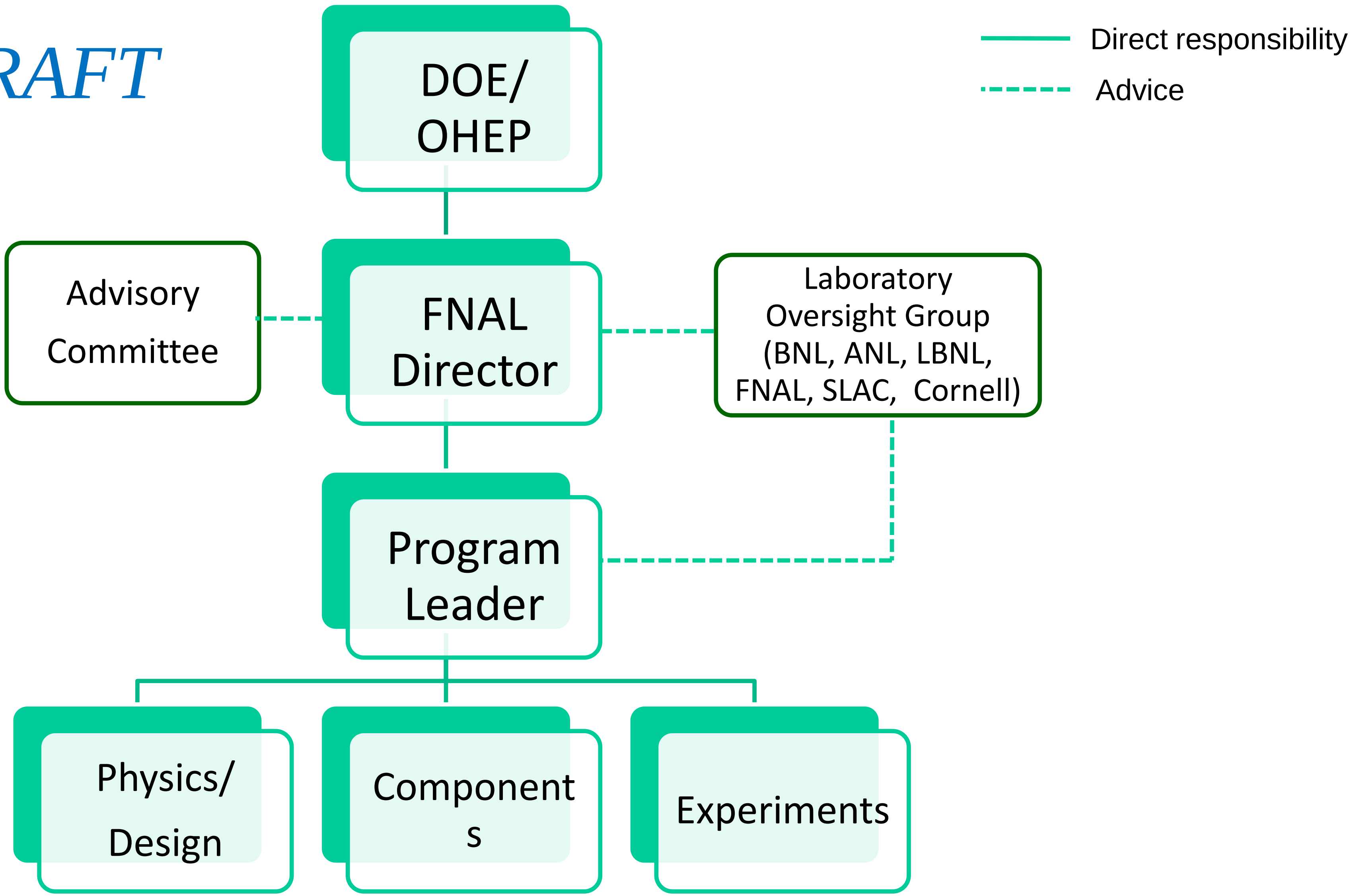

Conclusions

- Although this has been a stressful year due to funding limitations, much progress has been made
  - MuCool - 19MV/m @ 201MHz
  - MERIT – 4MW Targetry demonstration
  - MICE – First beam
  - Much progress on the design and simulation for a Helical Cooling channel
  - Beginnings of a National program (&collaboration) on High Temperature Superconductor and its application in extreme-high-field magnets
  - On track for the first beam experiment in the MTA by year's end
  - IDS-NF has been launched
  - Developing the plan on how to deliver a feasibility study (ZDR) for a Muon Collider by around 2012